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Technical Report 158

SUMMARY OF WHITEOUT STUDIES

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by

J. R. Hicks

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U.S. ARMY MATERIEL COMMAND
COLD REGIONS RESEARCH & ENGINEERING LABORATORY
HANOVER, NEW HAMPSHIRE

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PREFACE

This is one of a series of reports of work on USA CRREL project: Whiteout Studies.

The work was performed by Mr. J. R. Hicks, Research Meteorologist, for the Environmental Research Branch, Dr. R. W. Gerdel, Chief, and the Research Division, James A. Bender, Chief.

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SUMMARY

Previous whiteout work done by CRREL from 1954 to 1962 is outlined and field studies by CRREL in 1963, including instrumentation, seeding materials, and test procedures are discussed. The 1963 experiments were designed to test the feasibility of using recently developed rockets (cold-propellant and solid-fuel types), continue the investigation of tethered balloon techniques, and field test the organic compound phloroglucinol, which was recently found to be an effective ice-nucleating reagent in the laboratory. A ground-based system for fog dispersal is feasible. Of the many systems tested, the CRICKET is the most promising. It can be moved easily to any suitable area, penetrate fog or clouds to heights of about 4000 ft, and is less expensive to buy and operate. It was concluded that better tracking and observing techniques are needed to determine if the seeding is effective. Monitoring a test from the ground in a dense low fog is difficult because (1) observers easily get lost, and (2) variable air movements make uncertain the drift of the seeded area.

SUMMARY OF WHITEOUT STUDIES

by

J. R. Hicks

INTRODUCTION

Whiteouts* have long been a bane to Arctic explorers, inhabitants of cold regions and, in fact, all persons who are required to live and move about in snow-dominated regions.

Until the last two decades this condition was tolerated, and activities were geared to the weather, i.e., when visibility was reduced to the point where orientation became difficult, surface and air activity was reduced accordingly. However, with the advent of new theories of weather modification and the increasing military requirements for maneuvering in arctic regions, interest was aroused in the possibility of clearing areas of arctic whiteout which were caused by low-level stratus clouds or fog.

This particular type of whiteout (Gerdel and Diamond, 1956) appeared to lend itself to artificial nucleation by seeding for a number of reasons: First, it was nearly always composed of undercooled water droplets. Second, it usually appeared at altitudes within reach of ground-based equipment or Army aircraft. Third, it occurred frequently during periods of light winds, thus making it easier to take observations.

Furthermore, since these whiteouts occurred frequently in areas of the Greenland Ice Cap in which United States Army Cold Regions Research and Engineering Laboratory (USA CRREL)† was already doing research on other projects, little additional logistic support was needed.

RESUME OF PREVIOUS WORK BY USA CREEL

1954-57

Scientific investigations of arctic whiteouts were begun by USA CRREL in the summer of 1954. During a trip by tractor train across the Greenland Ice Cap to a point 200 miles east of Thule many whiteouts were observed by USA CREEL scientists who subsequently classified them in five categories: overcast, water-fog, ice-fog, blowing snow, and precipitation whiteouts. Investigations for this and the following year were limited to actual observations of whiteouts and a review of climatological data. Particular emphasis was placed on the frequency and duration of fogs, and the wind and temperature regimes during periods of whiteout (Gerdel and Diamond, 1956).

In 1956 and 1957 the physical properties of the Greenland fog whiteouts were investigated by USA CRREL scientists. The number, size and distribution of fog and

---

* Whiteout: An atmospheric condition occurring over a continuous snow surface during periods of fog or overcast sky. Incoming light is scattered and reflected many times causing a complete lack of visual contrast between the sky and the snow surface. This results in poor depth perception, reduced visibility, and apparent lack of surface features.

† USA CRREL was formed in 1961 by combining the U. S. Army Snow, Ice and Permafrost Research Establishment (USA SIPRE) with the Arctic Construction and Frost Effects Laboratory (USA ACFEL). Thus, in this report, any work of USA CRREL prior to 1961 was actually performed by USA SIPRE.

cloud particles were measured; replicas of ice crystals were obtained; liquid and total water content of the air was calculated; visibility studies were conducted; air temperature and radiation data were obtained; and atmospheric nuclei were investigated.

Synoptic weather data prior to, during, and after whiteouts were studied, and an analysis of moisture balance during each of two selected cases was made.

For the final effort in 1957, a series of seeding experiments using ground-based silver iodide generators was performed. Results of these tests were inconclusive although several snow showers were observed to form downwind. It was determined, however, that ground-generated silver iodide crystals could not penetrate the inversion layer which is usually present over the ice cap (Reiquam and Diamond, 1959).

1958

Sporadic seeding was done at the USA CRREL research sites in Greenland during the summer of 1958. Figure 1 shows the sequence of one of the tests which made use of a mortar shell and a silver iodide-impregnated "bomb." While nothing conclusive was observed at that time, it appears in retrospect that a snow shower which developed downwind from the site was a normal reaction which is to be expected when effective seeding is done.

In another series of experiments (Fig. 2) a -2C fog at Thule Air Base, Greenland, was seeded with dry ice carried aloft by free balloons. Proper height was obtained by a combination of balloons which were inflated to give predetermined rates of rise, and fuses which burned at known rates. During these tests several breaks in the fog were observed but it could not be determined if they were the results of seeding. These breaks filled in very rapidly and no conclusions were drawn as to the cause of their occurrence or disappearance. Further investigations were needed.

1959

Between 26 June and 27 July, temperature profiles, sodium chloride content, and droplet sizes were measured in nine whiteouts near the U. S. Army's research facilities, Camp Fistclench, located about 210 miles east of Thule AB, Greenland. Visibility, light transmission, and incident and reflected visible and infrared light were measured on 19 days. Later, between 31 July and 9 August 1959, the above parameters plus the albedo and nuclei content of two whiteouts were measured at the edge of the Greenland Ice Cap about 15 miles southeast of Thule AB. (USA SPIRE, 1960).

1960-62

In 1960, USA CRREL entered into a contract with Cornell Aeronautical Laboratories (CAL) to:

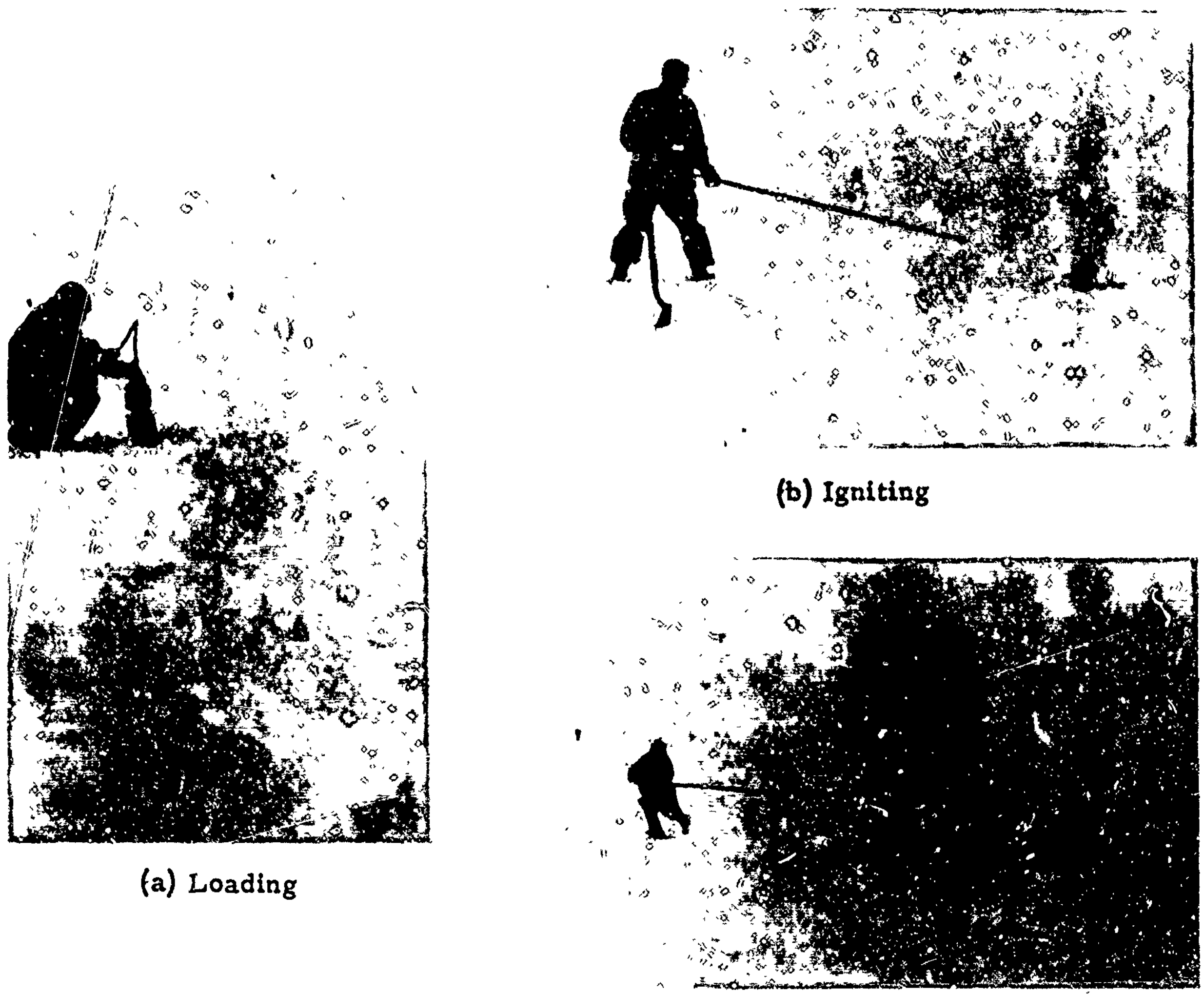
(1) Design experiments to determine the extent to which Greenland whiteouts can be dissipated by conventional techniques.

(2) Insofar as possible, determine optimum methods for dispersal of seeding materials using both ground-based and airborne dispersal techniques.

Field work was conducted at Camp Fistclench. These experiments were very successful and laid the groundwork for the development of a strictly ground-based system (Jiusto and Rogers, 1961).

Concurrently with these studies USA CRREL was conducting research on fog particles in northwest Greenland (Kumai and Francis, 1962).

The original contract with CAL was modified in 1961 to include laboratory testing of new whiteout modification materials and investigation of specialized seeding equipment (e.g., a dry ice pellet maker), placing special emphasis on the use of Army drones, mortars, and tethered balloons.



(a) Loading

(b) Igniting

(c) Firing

Figure 1. Silver iodide seeding with mortar.

Conclusions drawn from these studies were that the available types of Army drones were far too complicated and require too much logistic support to be considered feasible. The rockets were thought to have possibilities and several types were investigated. Included in the study were bazooka motors which were available as on-the-shelf items and civil defense rockets which could be adapted to cloud-seeding requirements.

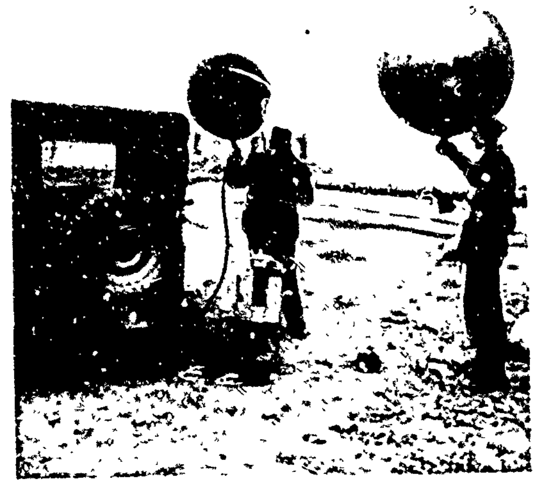
The findings were reported by CAL in their annual summary report (Mee and Eadie, 1963).

In 1962 the basic contract with CAL was again modified to include the following additional work:

1. Continue development of a small dry ice pellet maker.

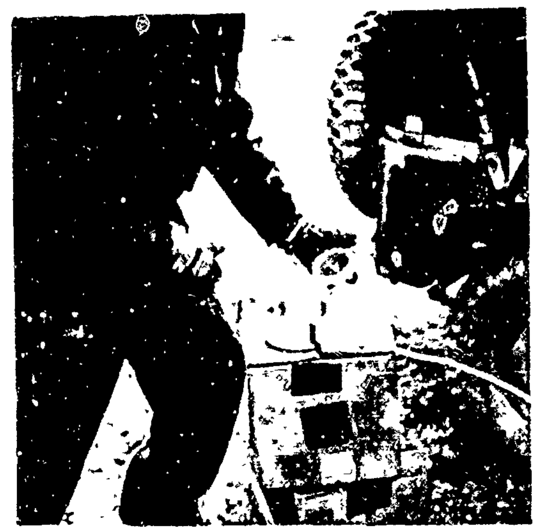
2. Determine experimentally the practicability of suppressing whiteouts with rocket-or mortar-borne seeding material.

a. Undercooled fog

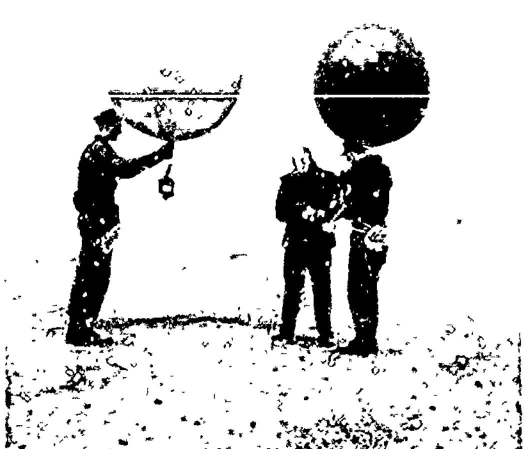


b. Preparing balloons

c Making dry ice



d. Removing dry ice from machine



e. Igniting fuse

f. Releasing balloon

Figure 2. Fog seeding at Thule, Greenland.

3. Continue the theoretical and experimental investigations of the seeding effectiveness of dry ice, with emphasis on relationship of pellet size to fall velocity and cloud thickness.

A final report covering the above work and a summary of all the previous work done by CAL under the basic contract was submitted to USA CRREL (Jiusto and Mee, 1964).

FIELD STUDIES BY USA CRREL (1963)

Purpose

The goal of all research in whiteout modification studies is the achievement of a simple and economical technique for clearing areas of fog or low-level stratus clouds. Hence, as each new reagent or vehicle is discovered or developed in the laboratory, it is later given a field test to determine its suitability in an operational system.

The 1963 experiments were designed to (1) test the feasibility of using newly developed rockets (cold-propellant and solid-fuel types), (2) continue investigation of tethered balloon techniques, and (3) test under field conditions the organic compound phloroglucinol, which recently had been found to be an effective ice-nucleating reagent in the laboratory.

Description of field installation

The 1963 field research was conducted by USA CRREL personnel at the U. S. Army's research facility at Camp Century, Greenland, some 137 miles east-northeast of Thule AB, during August and early September. The coordinates of this site are 77° 10' N, 61° 08' W, and the elevation is about 6310 ft above mean sea level.

The test site was located about 2500 ft southeast and upwind of the main camp to provide an unrestricted area in which to launch rockets safely, and to insure that only uncontaminated air would flow across the sampling area.

A wanigan was used as headquarters and field laboratory at the test site. Nearby, a raised storage pad was constructed on which the CO_2 cylinders and other project material were stored. A balloon hangar 18 x 50 ft (not including the access ramp) and 16 ft deep was cut into the snow to provide shelter for the blimp balloon and sampling equipment (Fig. 3).

Power for this field facility was obtained from a 3-kw diesel powered generator which was installed on a raised platform on the lee side of the wanigan. It was kept in continuous operation during the summer test period except for periods of maintenance.

A 3-mile trail was laid out upwind from the wanigan and marked with flags at 50-yard intervals (Fig. 4). At the upwind end, a 1-mile trail ($\frac{1}{2}$ mile on each side of the center and oriented normal to the long leg) was laid off and flagged. The flag poles were numbered so that orientation was assured even under severe whiteout conditions.

Weather

Surface temperatures at Camp Century during summer and early fall are generally below freezing, ranging from a minimum of about -23.3C to a maximum of about 0C. Above-freezing temperatures occur at times, and light rains may occur infrequently.

Temperature soundings usually show a marked inversion in the lowest 400-600 ft. A temperature difference of as much as 9C is not uncommon. This persistent inversion precludes the use of ground-based generators from which the nucleating agents are dispersed by diffusion into the atmosphere such as have proven successful in some western states.

The wind at the surface is usually from the southeast at 10-15 knots, increasing frequently to speeds greater than 40 knots during which time there is much blowing and drifting snow. During warming trends and periods of precipitation, the wind

Figure3. Balloon hangar, project wanigan, and raised storage pad.

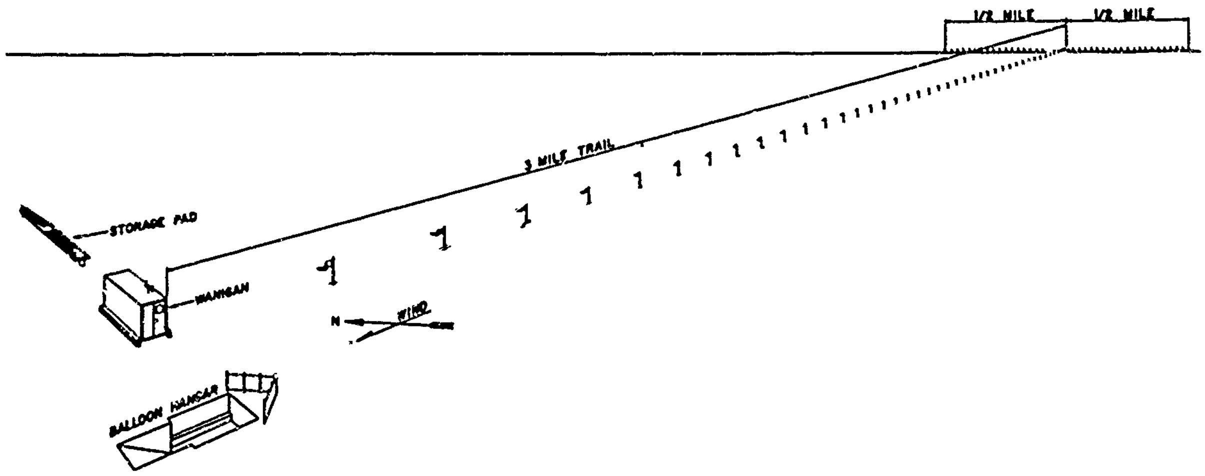


Figure 4. Plan layout of test area.

usually shifts to a more southerly direction. Wind may also shift with increasing height, veering as much as 180° in 800 ft.

Restricted visibility of varying degrees is commonly experienced in this area. Fog-type whiteout frequently reduces the visibility to only a few yards while drifting or blowing snow may reduce the visibility to less than a few feet.

Figures 5 and 6 show the duration of fog in the camp Century area for the period of record, May 1960 - June 1963. Only fog which occurred when the wind was less than 15 knots was considered since greater windspeed would have precluded the launching of rockets and subsequent observation of effects of seeding tests.

INSTRUMENTATION

Blimp-balloon

A Seyfang 1004 helium-filled blimp-balloon was used to lift the temperature probes and the cloud particle samplers. This balloon is made of neoprene-impregnated nylon, is about 30 ft long by 10 ft in diameter, has a gas capacity of about 1200 ft^3, and can carry a payload of about 25 lb at the 6300-ft elevation of Camp Century.

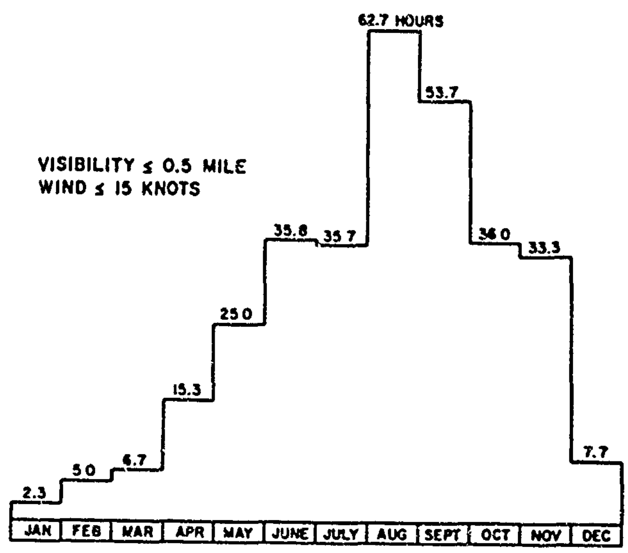
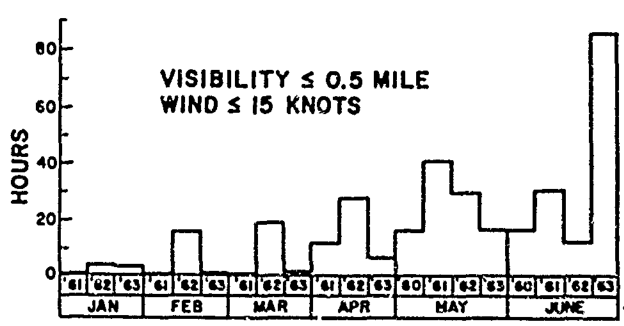


Figure 5. Average monthly duration of weather conditions considered suitable for seeding (Camp Century 1960-1963).



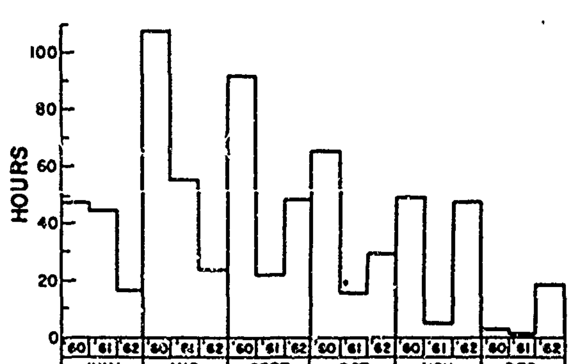


Figure 6. Monthly duration of weather conditions considered suitable for seeding at Camp Century for the period of record (1960-1963).

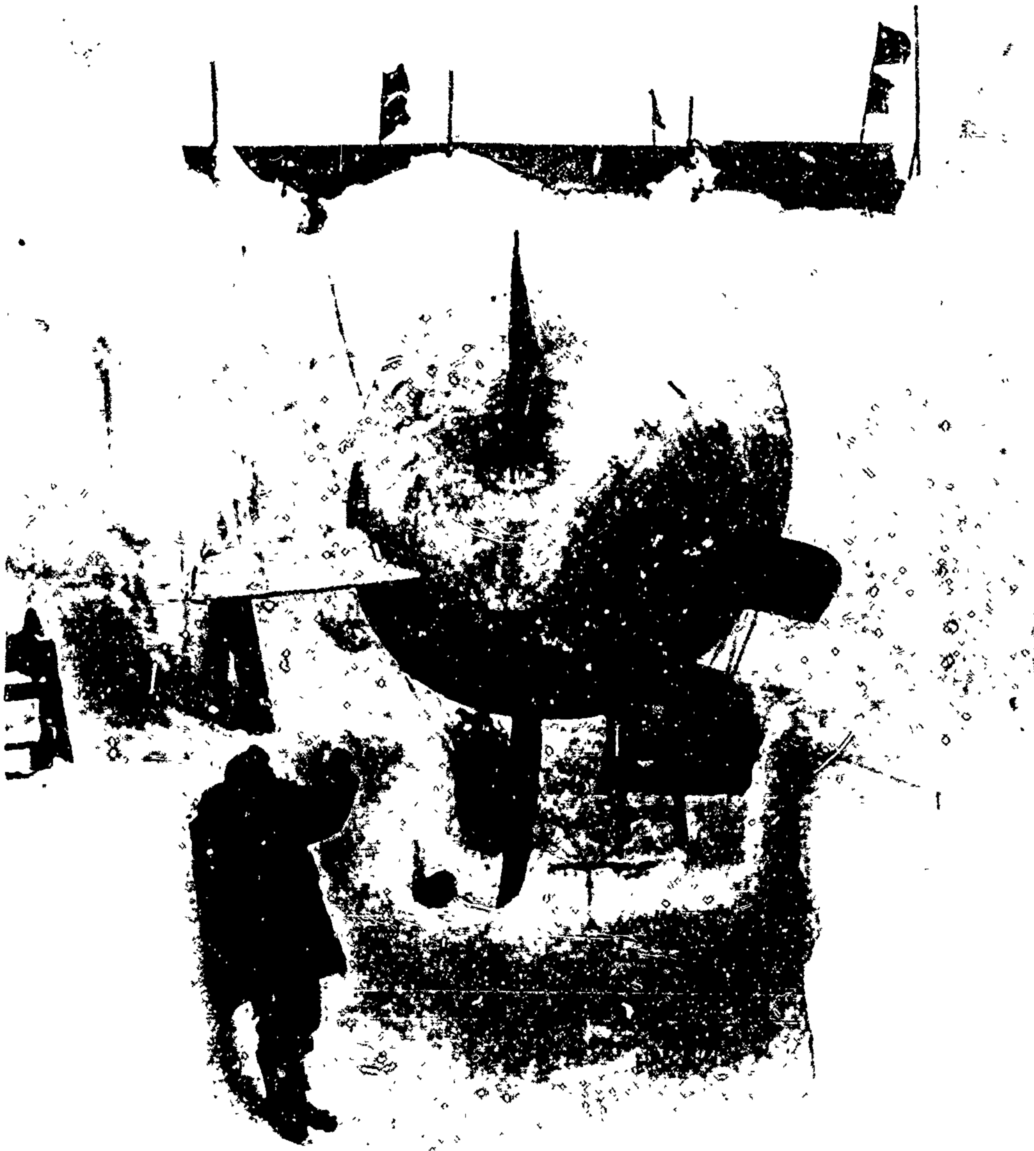


Figure 7. Balloon and hangar.

A hand-operated winch system was installed at one end of the hangar (Fig. 7). The 500 lb test nylon tethering line was marked at 10-ft intervals so that an estimate of the balloon's height could be obtained.

Temperature gradient sensor

A fast response thermistor probe (Tele-Thermometer) was used to sense the temperature at frequent levels up to a maximum altitude of 1500 ft. Since no recording system was installed, temperatures were read from the direct-indicating dial.

Cloud-droplet sampler

Samples of clouds or fog were obtained with a two-stage impactor described by Kumai and O'Brien (1964). The impactor is carried aloft to the desired height by a tethered balloon. When a sample is desired, a valve is actuated, electrically, allowing air to be drawn through two small openings, each of which directs the air flow to a silicon-oil-covered collection glass.

The collected samples are then photographed.

Replicas

Replicas of ice crystals and snow flakes were obtained by placing a microscope glass slide coated with a Formvar solution on a surface on which the particles were falling. After a sufficient number of samples were "caught" on the slide, it was covered and allowed to harden for a few hours.

Daily meteorological data

Routine meteorological data were obtained from the U. S. Army Meteorological Detachment stationed at Camp Century.

SEEDING MATERIALS

Solid CO_2 (dry ice)

Dry ice, at the present time, is the best and most reliable seeding agent for undercooled clouds and fog; however, it imposes a logistics problem in remote areas for it cannot be stored for long periods and must, therefore, be manufactured from liquid CO_2 immediately before use. About 15 lb of dry ice can be made from one 50-lb cylinder of liquid CO_2 (165 lb gross weight) at the test site temperatures.

For these studies, "Snowman" dry ice machines were used to manufacture 12-oz cakes. One such cake could be made each 45-60 sec. Some difficulty with the machines was experienced when a large number (20-30) of the cakes had to be manufactured at one time. Apparently there is enough moisture in the "welder's grade" CO_2 to cause ice to form in the orifices of the system and to stop the flow of liquid CO_2. "Bone-dry" CO_2 is recommended for dry ice making but is sometimes difficult to obtain.

Just prior to the launching of the rocket, the large cakes of dry ice were put through a hand-operated ice crusher (Alaskan No. 1) which broke them into particles ranging in size from powder to irregular pieces about $\frac{3}{4}$ in. maximum diameter.

Some test flights were made to determine the compaction characteristics of the dry ice under various acceleration loadings. It was found that when the fine particles were not removed severe compaction occurred and the cargo was discharged in one chunk. When the fines were eliminated by sieving through a $\frac{1}{4}$-in. mesh screen, no such compaction occurred.

Phloroglucinol

One of the most promising ice-nucleating agents of the organic compounds is phloroglucinol: $C_6H_3(HO)_3 \cdot 2\,H_2O$. This compound has been shown to be effective in the laboratory at temperatures as high as -2C (Langer and Rosinski, 1962).

The crystals of commercial-grade phloroglucinol are quite large ($\simeq$200 μ) and must be greatly reduced before being used as a seeding agent. A particle size of 0.5 μ is considered the optimum, but is very difficult to obtain as a dry powder.

Figure 8 shows electron microscope photographs of some crystals which were obtained by ball-milling the commercial-grade dry crystals. Figure 9 shows the particle size distribution for the phloroglucinol used in these tests.

Free flow of the phloroglucinol was assured by combining it with a colloidal silica and storing the mixture in a waterproof container until just prior to use, at which time it was loaded into the cargo compartment of the rocket.

This procedure was not practical for large-scale operations since the phloroglucinol-silica mixture was very difficult to handle. It was prone to blow around in the slightest draft and to permeate the air in the wanigan where it was being loaded into

a. Magnification, X1480 b. Magnification, X16, 300.

Figure 8. Electron microscope photographs of phloroglucinol particles.

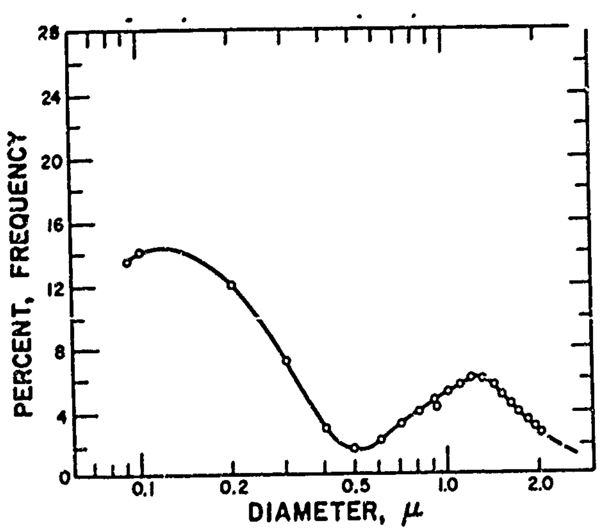


Figure 9. Particle size distribution (phloroglucinol).

the rockets. Also, some of the mixture leaked out of the cargo compartment and into the mechanical timer sections of the rockets.

TEST PROCEDURES

Actual seeding tests were begun on 8 August and continued until 4 September 1963. Prior to that, 16 July to 8 August 1963, the camp was established, equipment checked, and personnel made familiar with the handling of the rockets and launching equipment.

Four systems were used for dispersing the seeding material into the clouds: 1) The cold-propellant rocket (CRICKET); 2) The launch tube of the CRICKET system (for low-level clouds or fog); 3) Suspension of dry ice on tethered balloons or bamboo poles; 4) Balloons to carry aloft plastic bags which contained either dry ice or phloroglucinol in which No. 8 blasting caps were embedded. These were designed to disperse the seeding material at predetermined heights.

Cold-propellant rockets (CRICKET)

This system consisted of a CO_2-launched-and-propelled rocket having a payload capacity of approximately 1 lb and a capability of attaining heights of about 3000 ft. Mechanical timers, activated by the launch acceleration, could be set between 0 and 30 sec. These timers activated the parachute recovery system and the cargo compartment door.

Description of rockets. A Texaco Experiment Incorporated Model III CRICKET (Cold Rocket Instrument Carrying Kit) was modified to provide payload compartments of two sizes: 2.5 x 7.0 in. and 2.5 x 13.0 in. The shorter compartment was simply a standard parachute recovery section, less parachute; and the longer compartment was a custom-built section having a door opening the full length and covering one-half (180°) of the cylinder.

The rocket motor section was the same for both configurations, measuring 24.5 in. long by 2.5 in. in diameter. In use, it was usually charged with 800 cm^3 of acetone into which liquid CO_2 was introduced just prior to launch. Performance was varied by using different combinations of acetone and CO_2.

Figure 10 is a photograph of a modified rocket with the larger cargo compartment and Figure 11 shows an exploded view of the basic rocket.

Launcher. A special launcher is required for this type of vehicle. It consists of a base into which two 10-lb cylinders of CO_2 are mounted, a 10-ft launch tube, and the valves and gages needed to charge the rocket and to eject it from the launch tube.

For use in Greenland a launcher was mounted on a 1-ton sled along with several 50-lb cylinders of CO_2 (Fig. 12). Externally mounted CO_2 cylinders were used to increase the number of launches which could be made without the need for replacing the cylinder. About five launches can be obtained from each 10-lb CO_2 cylinder, whereas more than 25 launches can be had from each 50-lb cylinder.

A typical launch proceeded as follows:

a. The launching equipment was positioned upwind a distance equal to 30 min of windflow; e.g., for a 6-mph windspeed, a distance of 3 miles was used.

b. Eight hundred cubic centimeters of acetone were poured into each rocket motor compartment and a nozzle plug was installed. (The nozzle plug is held firmly in place by the folded rocket fins which are prevented from opening by the launch-tube walls. When the rocket leaves the tube, the internal pressure forces the plug out, positioning the fins, thus giving stability to the rocket and allowing the propellant to be discharged and provide added thrust to the unit.)

c. Dry ice was manufactured in the "Snowman" ice machine and chopped to irregularly shaped chunks, ranging in size from powder to $\frac{3}{4}$ in. diam, in an "Alaska Ice Crusher." The fines were sieved out through a $\frac{1}{4}$-in. mesh screen to prevent compaction during launch, and about 1 lb of the remaining chunks was placed in the cargo compartment of the rocket.

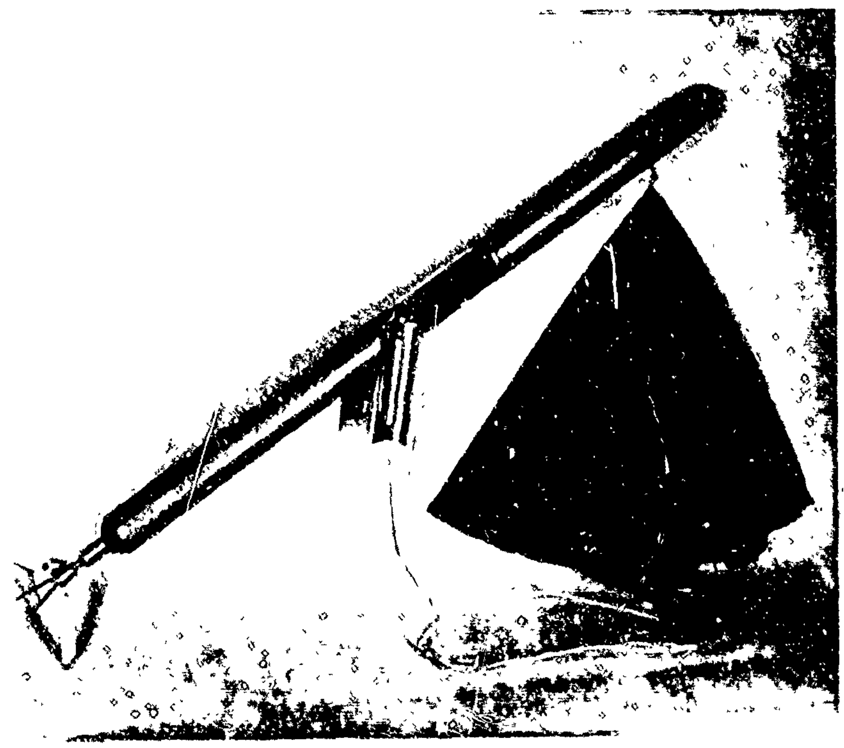


Figure 10. CRICKET rocket with long cargo compartment.

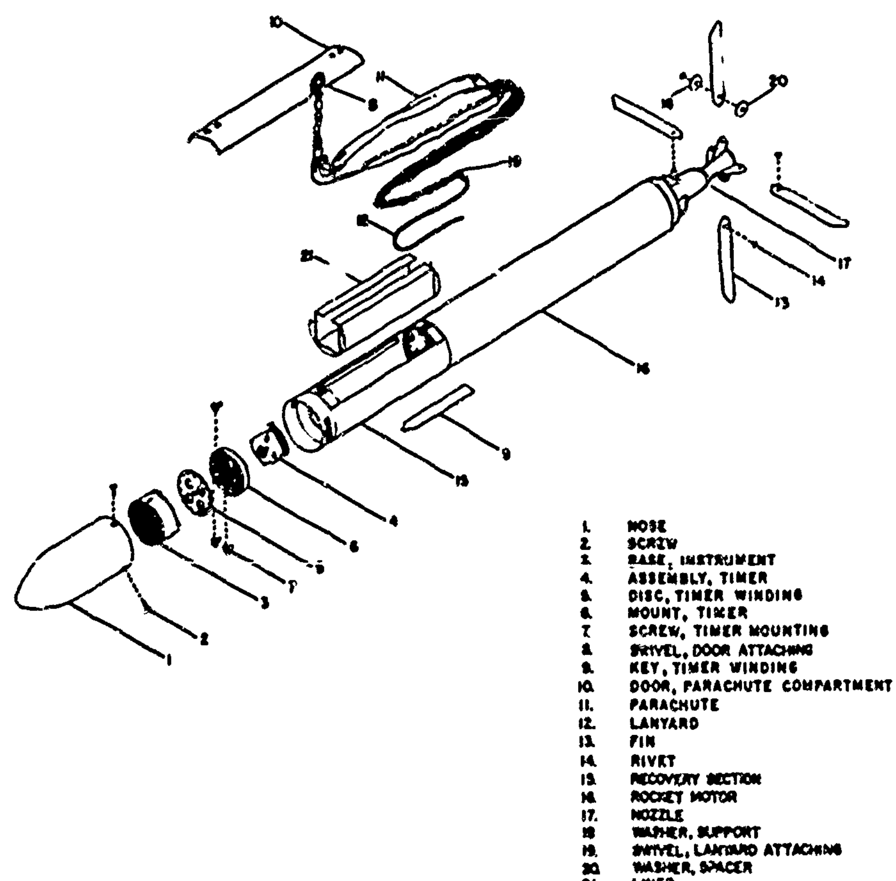


Figure 11. CRICKET rocket, exploded view.

Figure 12. Launcher, rockets and CO_2 supply mounted on a 1-ton sled.

d. Previously designed performance curves were consulted to determine the launch pressure, the rocket charge pressure, and the time to apogee for the height needed for the current weather conditions.

e. The mechanical timers were set: usually to release the parachute near apogee and release the cargo 2 to 3 sec later. (This sequence can be altered to release the cargo while the rocket is still in motion in order to spread the material over a longer path.)

f. Finally, the rocket was placed in the launch tube, the launch pressures set to the predetermined values, and the rocket fired.

Results of tests, series C. Fourteen groups of rocket flights were conducted in this series: some to test the equipment and check out personnel in the techniques of rocket handling and launching, and the remainder for conducting seeding experiments using either dry ice or phloroglucinol as the ice-nucleating reagents. Appendix A contains the tabulated data for this series. An analysis of each group of tests follows.

C 1 (flights 1-29), 8 August 1963: These flights were made to familiarize the project personnel with the operation of the rockets and launcher, and to test the rocket performance under different load and launch conditions.

The performance curves supplied with the rockets were of little value at the test site since they were drawn for sea-level conditions and for temperatures greater than +21C. At these temperatures the liquid CO_2 pressure is about 900 psi, but at the ambient temperatures at the site, i.e., -23C to 0C, the liquid CO_2 pressure is only 257 to 525 psi, thus greatly reducing the maximum performance of the rockets. Some further loss of performance was encountered as each successive rocket was fired because of the additional cooling of the CO_2 supply bottles as the gaseous CO_2 was drawn off.

To offset this diminished performance, a helium-boost system was tested. This provided a system for charging the rocket propellant with a greater amount of liquid CO_2. However, after this series of tests was completed it was determined that the performance with CO_2 alone was satisfactory and the helium system was not needed.

Launch pressures ranging from 50 to 400 psi, and propellant charge pressures between 320 and 525 psi were used during these tests.

Parachute and payload compartment release timers were tested between a 4-sec minimum and a 16-sec maximum.

The standard 4-ft parachute which was supplied with the rocket let the rocket descend rather slowly. This allowed a long drift downwind and subsequent greater recovery problems. Hence, two flights were made in which half of the parachute was tied off (reefed). Although this decreased the drop time, the gain was considered insignificant.

The over-all performance of this series was considered good even though there were six malfunctions, each due to failure of the nozzle plug to eject. The cause of these failures was found to be insufficient liquid CO_2 being pumped into the rocket motor compartment because the crew was unfamiliar with the proper use of the charging pressure control system.

C 2 (flights 30-49), 14 August 1963: Nineteen rockets charged with a phloroglucinol-cabosil mixture were fired into a cloud layer whose base was about 375 ft and whose top was an estimated 1500 ft.

No changes in the cloud structure were visible from the ground. Visibility remained the same before, during, and after seeding.

Conditions were generally poor for seeding as the overcast was of varying height and density. The wind was too strong to permit good observations to be made from the surface.

C 3 (flights 50-51), 15 August 1963: These flights were made to determine whether the launch accelerations would compact the dry ice particles into a single chunk. Sieved dry ice was used in a standard CRICKET compartment. The cargo-release was secured to prevent the release of the dry ice so that it could be examined when it returned to earth.

No compaction of the dry ice was observed during these tests.

C 4 (flights 52-53), 15 August 1963: These two flights were made with a modified CRICKET having a fixed leather ring (pump washer) in place of the fins and a loose nose cone which would fall out after the parachute opened, dumping the payload. No propellant was used in the rocket.

Payload consisted of 750 g of dry ice containing fines.

With a launch pressure of 400 psi, these vehicles reached a height of about 700 ft which indicated that an acceleration of about 70 g's occurred at launch.

Severe compaction was noted, the resulting cylinder of dry ice being almost as hard as the original one before being crushed.

C 5A (flights 54-59) and C 5B (flights 60-63), 16 August 1963: These ten flights were made to determine the flight characteristics of the CRICKET at low launch pressures. Five were successful in all respects, two were successful but penetrated the overcast and could not be observed, and three were erratic in flight.

All rockets appeared to be somewhat unstable below 200 ft. Above that height, a speed was reached which permitted the stabilizing fins to become effective.

As launched at 50 psi, the lowest portion of the rocket is heavier than the nose section because of the liquid propellant. This tends to impose instability which can be overcome only by launching at high speeds, i.e., by use of launch pressures greater than 50 psi.

No compaction was evident at the accelerations present during these tests and the rockets discharged their loads with no difficulty.

C 6 (flights 64-76), 19 August 1963: Primarily, this series of flights was made to train the crew in continued seeding operations. Several areas for improvement were revealed, the most notable of which was in manufacturing a supply of dry ice. It was found that two dry ice machines were required to supply one launcher for continuous operation when a rocket is launched every 2 to 3 min.

Six rockets were lost because of inability to maintain visual contact. The strong wind apparently carried them along the snow surface after landing and they probably became covered with the drifting snow.

No results from these seedings were anticipated or obtained since the temperatures were above the range of effectiveness. Also, snow was already falling.

C 7 (flights 77-91), 21 August 1963: Fourteen rockets, some standard and some with long cargo compartments, were used to seed a fog layer with dry ice.

Seeding was begun at 2030 hours. Some brightening of the sky was observed at 2045 hours: ice needles appeared momentarily at 2055 and a small patch of blue sky appeared, but disappeared immediately. Horizontal visibility remained nearly constant during these tests.

Rocket performance was good; however, the minimum height obtainable was approximately 700 ft which was about 550 ft above the top of the fog. Dry ice falling through this layer lost much of its effectiveness by the time it reached the top of the fog.

C 8 (flights 92-96), 22 August 1963: Five rockets were used to seed a shallow, 75 to 100 ft, undercooled fog with dry ice.

Two rockets of this series were faulty: one had a leaking "O" ring and had to be aborted, the other one failed to release its cargo because of a failure of the mechanical timer.

As in series C 7, the minimum height of apogee was about 700 ft and, consequently, the seeding material was discharged too high above the top of the fog to be effective. Two factors are involved here: 1) The launch pressures must be high enough (> 50 psi) to start the timers. 2) The propellant charge must be great enough (> 150-200 psi) to eject the nozzle plug and set the fins for flight. Reduced apogee can be obtained by angle launching but this was not done because the height-angle relationship had not been determined prior to this series of tests.

No visible changes in the fog structure were observed during this series of tests.

C 9 (flights 97-106), 23 August 1963: Dry ice was discharged about 700 ft above the surface. This was the lowest consistent altitude which was obtainable without extensive modification of the basic rocket design, or revised launching techniques.

Seeding began at 0930. At 1000, after the fifth rocket had been launched, a slight clearing was observed directly overhead. However, the clearing was not definitely attributed to the seeding, since no change in cloud structure or falling snow particles were observed.

Much frost accumulated on everything exposed. The blimp-balloon became so heavy that it could not be used. The nylon tethering line took on a ³ in. diam frost covering. The thermistor line took on a very heavy coating of frost on the white and green section but very little on the red and black section.

All 10 rockets were recovered within a 300 yard diam circle, the center of which was about 250 yards from the launcher.

C 10 (flights 107-111), 23 August 1963: The purpose of this series was to try a new launch technique to reduce the height at apogee. The propellant chambers were charged only with 300 psi of gaseous CO_2. This pressure was enough to eject the nozzle plug, but would give only a small boost to the rocket. The heights reached averaged about 300 ft. Although this minimum height was a much-reduced one, it was still 150 to 200 ft above the top of the fog.

No clearing of the immediate area was observed. Probably no change took place since the temperature was near the top of the effective range of dry ice (-2 to -4C). Also, freezing rain was occurring at the time.

C 11 (flights 112-116), 23 August 1963: The flight characteristics of these five rockets were excellent. Four out of the five rockets entered the cloud and discharged the reagent either into or above the cloud, but with no visible results. The overcast was broken, but a clearing trend was in effect and the weather cleared shortly afterwards.

C 12 (flights 117-121), 23 August 1963: The weather was unsuitable for seeding because of the broken sky cover and the clearing trend - much blue sky was showing. However, it was thought that something might be gained by these tests.

The first two rockets (phloroglucinol) appeared to discharge their reagent several hundred feet above the cloud top, so the last three rockets (dry ice) were timed to delay the discharge of the cargo until nearer the top of the cloud.

About 15 min after the first flight a bright spot (sun pillar) appeared in one cloud; however, it could not be determined whether or not this was caused by seeding since the clouds were already broken and the sun was shining through other thin areas.

C 13 (flights 122-126), 24 August 1963: One of the five shots was observed to discharge its dry ice into a thin cloud. As the dry ice fell through the cloud, trails of ice crystals appeared. The cloud then took on a bright ice-crystal appearance in two areas. No precipitation, virga, or other changes were observed. The sky cover was already broken, so no positive evaluation of the effect of the seeding could be made.

C 14 (flights 127-135), 4 September 1963: Only gaseous CO_2 was used in the rockets. This was done to insure ejection of the nozzle plug and positioning of the fins for stability. No appreciable thrust was gained from the rocket motor; hence, low apogees could be obtained.

Seeding was begun at 2050 hours. At 2120 visibility increased to about 600 yards at a point 3 miles downwind from the seeded area. At 2135 visibility again diminished to about 250 yards.

As each rocket discharged its dry ice at a height of about 300 ft, white streamers of nucleated particles became visible and remained so for 2 or 3 minutes as they drifted downwind. No other reaction was noted immediately. Wind, drifting snow, and darkness prevented further observations.

Summary and conclusions, series C. One hundred and thirty-five cold-propellant type rockets were launched to determine the feasibility of this system for ground-based seeding of fog or low-level clouds.

Rocket performance was good. Of the total number of firings, there were only eleven malfunctions, and most of these occurred in the early phase when the men were learning to operate the equipment.

Recovery of the rockets was considered excellent. Ten were lost and never recovered; and about thirty were damaged. Most of these were repaired and put back into service. Parts are interchangeable, and much can be salvaged from damaged rockets.

Three men can manufacture the necessary dry ice, and launch a rocket about every 3 minutes. This rate is considered sufficient for most applications.

Logistics is a big problem in remote areas. To obtain 20 lb of dry ice, it is necessary to use a 165 lb cylinder of liquid CO_2. Hence, it is desirable to find other seeding material such as the phloroglucinol which has shown promise in the laboratory.

Only minor success was experienced in the actual seeding runs. The principle cause for this failure was the inability of this type of rocket to seed clouds which have an upper level below 700 ft. A modified launch technique was developed late in the season but suitable weather for seeding did not occur after that.

Launch tube dispersal techniques

The CRICKET vehicle in its present form was found to be unsuited for use on low-level fogs, i.e., fogs whose tops were less than 300 to 400 ft high. Since the CRICKET launch system had the capability of ejecting material out of its launch tube with such force that it could reach altitudes of 700 to 800 ft, a series of tests was planned which made use of this feature.

Basically, the launch system consists of a high-pressure gas reservoir, a quick-release valve and a 10 ft long, 2.5 in. diam tube (Fig. 13).

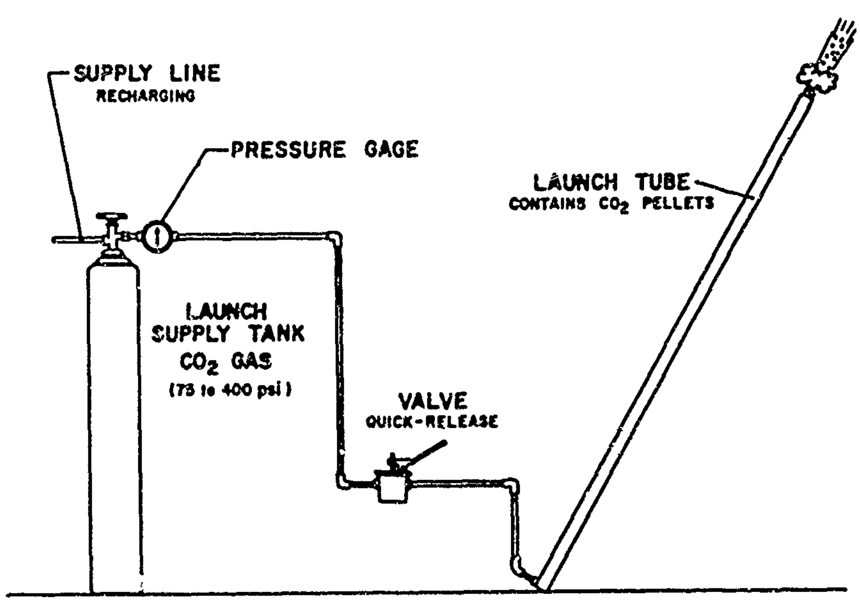


Figure 13. Pictorial diagram of launch system.

Dry ice pellets were poured into the launch tube and "blown" into the air. Using a launch pressure of 200 psi, the CO_2 pellets were "blown" to heights of about 150 ft.

Appendix B contains the tabulated data for this series.

Results of tests, series L.

L 1 (flights 1-5), 23 August 1963: The seeding material was shot into a fog about 150 ft thick having a temperature of about -5C. Some chunks were seen returning to the surface about 200 ft from the launcher. The total travel for some of these particles was about 400 ft.

No changes in the fog structure were noted.

L 2 (flights 6-16), 29 August 1963: Eleven shots were fired into a shallow fog layer. As each shot was fired, a dark plume appeared to a height of about 70 to 75 ft. This plume diffused as it drifted downwind and lost its identity about $\frac{1}{8}$ mile from the launcher. Near the launcher nucleated crystals appeared in the wake of the dry ice particles on the way up and down (Fig. 14).

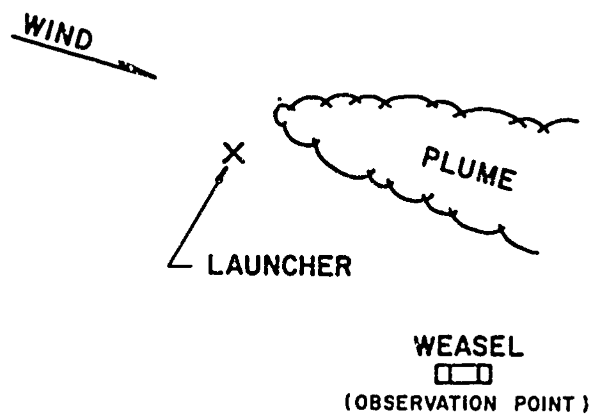


Figure 14. Aerial view showing locations of vehicle and launcher during launch-tube dispersal tests.

The fog burned off naturally at 0905 but directly downwind from the seeding launcher a band of dark-colored fog, about 100 ft thick, remained for 25 to 30 min. Efforts to photograph this were unsuccessful because of camera failure.

Balloons

Two systems for using tethered balloons to lift the seeding reagents were used.

The first method was to fasten 12-oz cakes of dry ice at 15-ft intervals along the balloon tethering line and fly the balloon at a height which was sufficient to put the dry ice within the fog layer. The wind blowing past the line would carry the supercooled fog particles past the dry ice where they would nucleate and form plumes of ice crystals downwind from each cake.

The second system was to use a captive balloon, tie a plastic bag of seeding material to it, place a No. 8 blasting cap in the plastic bag, light the powder fuse, and allow the balloon to rise to the desired height. The blasting cap would explode, spreading the seeding material in a column about 55 ft in diameter in the case of dry ice and about 15 ft in the case of phloroglucinol.

By using a double nylon line and suspending the blasting cap a few feet below it and about 30 ft from the balloon, repeated use could be made of this rig (Fig. 15).

An alternate system using balloons of known rise rates and fuses of known burning times could be employed. However, they can be used only once and the height of seeding is not under full control. For these reasons, this system was not tried during these field tests.

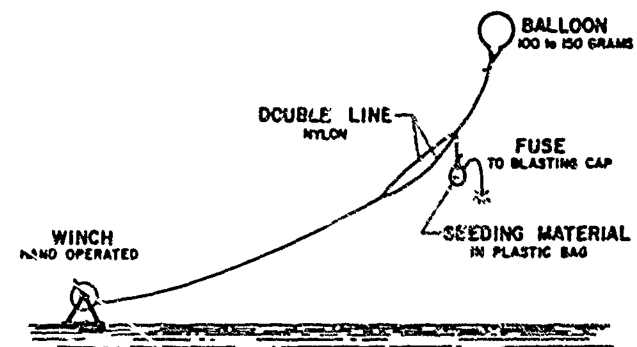


Figure 15. System for using tethered balloon and explosives for dispersing seeding materials.

Appendix C contains the tabulated data for this series.

Results of tests, series B.

B 1 (flights 1-5), 21 August 1963: Five plastic bags containing dry ice were exploded near the top of a very thin fog. No physical change in the fog was noted during or immediately after the seeding.

B 2 (flight 6): Ten 12-oz cakes of dry ice were suspended at 15-ft intervals along the nylon tethering line. The lowest cake was 15 ft above the surface.

Plumes of nucleated ice particles appeared at each cake of dry ice but no further reaction was noted either at the test site or at a point about 2 miles downwind.

Pole-suspended dry ice

Description of system. Ground fogs whose tops are under 50 ft occur frequently in the Camp Century area. Two such fogs were treated with cakes of dry ice placed on bamboo poles stuck into the snow. Appendix D contains the tabulated data for this series.

Results of tests, series S.

S 1, 29 August 1963: Ten 12-oz blocks of dry ice were held 10 ft above the surface on bamboo poles placed in the snow 50 ft apart and aligned normal to the wind.

A plume of ice crystals formed at each cake of dry ice. These plumes coalesced about 150 ft downwind.

Impactor samples showed some ice crystals present before seeding.

The fog was breaking up and clear zones appeared in other areas than the test sites so no conclusions can be drawn from this test.

One cake of dry ice lasted about 30 min at a windspeed of 5 knots and a temperature of about -11C.

S 2, 3 September 1963: Twenty 12-ft poles were stuck into the snow at 50-ft intervals along a line normal to the wind. A 12-oz cake of dry ice was mounted on the top of each pole.

A plume of ice particles emanated from each cake of dry ice and spread in diameter to about 10 ft at a point 150 ft downwind where it became indistinct. No other change in the fog was noted, even at a distance of $1\frac{1}{2}$ miles downwind.

Impactor samples showed a definite increase in the ice-crystal count after seeding.

CONCLUSIONS

These tests showed that a ground-based system for fog dispersal is feasible. The most promising of the many systems tested was the CRICKET. It is the most versatile (i.e., it can be moved easily to any suitable area); it can penetrate fog or clouds to heights of about 4000 ft; and it is comparatively cheap to buy and operate.

Better tracking and observing techniques are needed to determine if the seeding is effective. Monitoring a test from the ground in a dense low fog is very difficult for two reasons: (1) It is very easy for the observing personnel to get lost in the fog when they attempt to track a seeded section. (2) Air movement, even in a so-called calm, is variable and one cannot be certain which way the seeded area is drifting.

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APPENDIX A

Series C 1 (flights 1-29), vehicle: CRICKET.

Flight	Time 8 Aug 63	Launch pressure (psi)	Propellant pressure (psi)	Remarks
1	1500	200	missing	1 chute failed to emerge Timer set for 8 sec
2	1510	160	missing	Good flight
3	1530	200	400	Failure, nozzle plug failed to release
4	1545	210	400	Good flight
	9 Aug 63			
5	0850	400	400	Good flight
6	0900	390	400	Good flight
7	0905	360	400	Good flight
8	0910	350	400	Failure, nozzle plug failed
9	0915	330	440	Failure, nozzle plug failed
10	1120	385	525	Good flight
11	1125	360	375	Failure, nozzle plug failed
12	1128	340	300	Failure, nozzle plug failed
13	1130	320	500	Failure, nozzle plug failed
14	1140	300	420	Good flight. Some nucleation observed
15	1150	280	360	Good flight. Some nucleation observed
16	1340	340	380	Good flight
17	1345	320	350	Good flight
18	1350	300	350	Good flight
19	1355	280	350	Good flight
20	1357	50	400	Good flight
21	1400	50	360	Good flight
22	1405	50	360	Good flight
23	1410	50	360	Good flight
24	1413	50	400	Good flight
25	1416	50	380	Good flight
26	1419	50	320	Good flight
27	1425	110	360	Good flight
28	1430	100	360	Reefed $\frac{1}{2}$ parachute. Good flight
29	1435	100	320	Reefed $\frac{1}{2}$ parachute. Good flight

Series C 2 (flights 30-49)

<u>Date</u>: 14 August 1963, 0930-1100 hours

<u>Meteorological data</u>: Wind: SSE/14 knots
Cloud base: 375-1500 ft (variable)
Temperature (sfc): -5C
Visibility: Approx 3 miles before and after seeding

<u>Vehicle data</u>: Type: CRICKET — Long chamber
Reagent: Phloroglucinol - Cabosil: 1:2 by weight
Launch pressure: 100 psi
Propellant pressure: 360 psi

Series C 2 (flights 30-49) (Cont'd)

Flight data: Launch angle: 5° into wind
Launch interval: 4 minutes

Series C 3 (flights 50-51)

Date: 15 August 1963

Meteorological data: Wind: SSE/12 knots
Sky cover: Strato cu - 1500 ft base
Temperature: -5C
Visibility: Variable $\frac{1}{2}$ - 5 miles

Vehicle data: Type: CRICKET — Standard cargo compartment
Reagent: Dry ice, > $\frac{1}{4}$ in. < 1 in., approx 10 oz/flight
Launch pressure: 200 psi
Propellant pressure: 380 psi

Flight data: Launch angle: 10°
Apogee: Estimated 1500 ft

Series C 4 (flights 52-53)

Date: 15 August 1963, 1600 hours

Meteorological data: Wind: SSE/12 knots
Sky cover: Strato cu; base at 1500 ft est
Temperature: -5C

Vehicle data: Type: Non-propellant type — SLUG.
Weight, empty: 800 grams
Weight, cargo: 750 grams (dry ice)(containing fines)
Total weight: 1550 grams
Launch pressure: 400 psi

Flight data: Est acceleration: 70 g
Launch angle: 10° into wind

Series C 5A (flights 54-59)
Series C 5B (flights 60-63)

Date: 16 August 1963, 1400 hours

Meteorological data: Wind: Sfc - SE/12 knots
1500 ft - SSE/16 knots
Sky cover: Clear to partly cloudy
Temperature: -3.3C
Visibility: 7 miles

Vehicle data: Type: CRICKET — Standard
Launch pressure: 50 psi for flights 54-59
100 psi for flights 60-63
~~Propellant pressure: 380 psi~~
Acetone: 800 cm³
Cargo: A 350-cm cake of dry ice was run through a No. 1 Alaska Ice Crusher, sifted on a $\frac{1}{4}$-in. mesh screen, and the remains (approx 300 g) put immediately into the rocket.

Flight data: Launch angle: 5° into wind
Acceleration: 20 g (estimated) for flights 54-59
30 g (estimated) for flights 60-63

Series C 6 (flights 64-76)

Date: 19 August 1963, 1430 hours

Series C 6 (flights 64-76) (Cont'd)

Meteorological data: Wind: SE/11 knots - gusts to 26 knots
Sky cover: Low stratus and strato cu. Variable height of base: 50 - 1500 ft
Temperature: -1.4C
R. H: 82%
Visibility: Variable, $\frac{1}{3}$ mile - 3 miles, light snow flurries occurring. Drifting snow

Vehicle data: Type: CRICKET — Standard
Launch pressure: 50 psi
Propellant pressure: 320 psi
Seeding material: 280 grams. Dry ice ($>\frac{1}{4}$ in. $<\frac{3}{4}$ in.)
Acetone: 800 cm^3

Flight data: Launch angle: 5° into wind
Apogee: 1400 ft (est)
Parachute timer: 10 seconds
Load release: 14 seconds (point release)

Series C 7 (flights 77-91)

Date: 21 August 1963, 2030 hours

Meteorological data: Wind: Calm
Sky cover: Ground fog approx 100 ft thick
Temp:

Sfc	- 9.4C	700 ft	-8.8C
100 ft	-10.0C	800 ft	-8.6C
200 ft	-10.0C	900 ft	-8.5C
300 ft	-10.0C	1000 ft	-8.4C
400 ft	-10.0C	1100 ft	-8.2C
500 ft	-10.0C	1200 ft	-8.1C
600 ft	- 9.4C		

R. H. (sfc): 100%
Visibility: 200 yards
Droplet sizes (diam, μ): Min 14.3, Max 67.0, Mean 32.5.
Liquid water content: 0.189 g/m^3

Vehicle data: Type: CRICKET — Standard and long compartment (mixed)
Cargo: 250-300 grams CO_2 ($\frac{1}{4}$ - $\frac{3}{4}$ in.)
Launch pressure: 50 psi
Propellant pressure: 300 psi
Acetone: 800 cm^3

Flight data: Parachute timing: 7 sec
Cargo release timing: 10 sec (point release after apogee)
Launch interval: 4 min
Launch angle: 5° into wind

Series C 8 (flights 92-96)

Date: 22 August 1963; 0015 hours

Meteorological data: Wind: NNW/5 knots
Sky cover: Ground fog, 75 - 100 ft thick
Temp:

Sfc	- 6.1C	600 ft	-8.8C
100 ft	-10.0C	700 ft	-8.6C
200 ft	-10.0C	800 ft	-8.2C
300 ft	-10.0C	900 ft	-8.3C
400 ft	-10.0C	1000 ft	-8.5C
500 ft	- 9.6C	1100 ft	-8.4C
		1200 ft	-8.3C

R. H: 100%
Visibility: 200 yards

Series C 8 (flights 92-96) (Cont'd)

Vehicle data: Type: CRICKET — Long compartment
Cargo: Approx 400 grams dry ice ($\frac{1}{4}$ - $\frac{3}{4}$ in.)
Launch pressure: 75 psi
Propellant pressure: 300 psi
Acetone: 800 cm^3

Flight data: Launch angle: 5° from vertical, into wind
Parachute release time: 7 sec
Cargo release time: 10 sec
Apogee: 700 ft (est)

Series C 9 (flights 97-106)

Date: 23 August 1963, 0930 hours

Meteorological data: Wind: Calm to 3 knots SSE
Sky cover: Fog approx 150 ft thick

Temp:			
Sfc	-5.0C	600 ft	-5.6C
100 ft	-3.8C	700 ft	-5.4C
200 ft	-3.9C	800 ft	-4.8C
300 ft	-4.4C	900 ft	-4.8C
400 ft	-5.2C	1000 ft	-4.8C
500 ft	-5.0C	1100 ft	-4.9C

R. H: 100%
Droplet sizes (diam μ): Min 12, Max 84.3, Mean 49
Precipitation: Some freezing rain. Few snowflakes observed before, during and after seeding
Visibility. 150 yards
Much rime forming on tethering line of balloon

Vehicle data: Type: CRICKET — Long compartment
Cargo: Approx 400 grams dry ice ($\frac{1}{4}$ - $\frac{3}{4}$ in.)
Acetone: 800 cm^3
Launch pressure: 75 psi
Propellant pressure: 300 psi

Flight data: Parachute time: 7 sec
Cargo release time: 12 sec
Apogee: 750 ft (est)
Launch interval: 4 min

Series C 10 (flights 107-111)

Date: 23 August 1963, 1030 hours

Meteorological data: Wind: Calm to 3 knots SSE
Sky cover: Fog 150 ft deep (est)

Temp:			
Sfc	-4.4C	600 ft	-5.6C
100 ft	-3.8C	700 ft	-5.4C
200 ft	-3.9C	800 ft	-4.8C
300 ft	-4.4C	900 ft	-4.8C
400 ft	-5.2C	1000 ft	-4.8C
500 ft	-5.0C	1100 ft	-4.9C

R. H: 100%
Precipitation: Some freezing rain, interspersed with snowflakes, observed before, during and after seeding
Visibility: 150 yards

Series C 10 (flights 107-111) (Cont'd)

Vehicle data: Type: CRICKET — Long compartment
Cargo: Approx 350 grams of dry ice ($\frac{1}{4}$ - $\frac{3}{4}$ in.)
Acetone: None
Launch pressure: 150 psi
Propellant pressure: 300 psi (gaseous CO_2)

Flight data: Parachute opening time: 4 sec
Cargo release time: 7 sec
Apogee: 300 ft (est)
Launch interval: 4 min

Series C 11 (flights 112-116)

Date: 23 August 1963, 1345 hours

Meteorological data: Wind: Sfc calm
1500 ft SW/5 knots (est)
Sky cover: Strato cu (broken) base at 1500 ft (est), top at 1700 ft (est). A clearing trend was manifest
Temp:

Sfc	-5.7C	600 ft	-5.6C
100 ft	-3.8C	700 ft	-5.4C
200 ft	-3.9C	800 ft	-4.8C
300 ft	-4.4C	900 ft	-4.8C
400 ft	-5.2C	1000 ft	-4.8C
500 ft	-5.0C	1100 ft	-4.9C

R. H. (sfc): 100%
Visibility: Variable, $\frac{1}{2}$ mile to 7 miles

Vehicle data: Type: CRICKET — Standard length
Cargo: Phloroglucinol, commercial grade, ball-milled to reduce the size of the particles (Fig. 8, 9)
Launch pressure: 75 psi
Propellant pressure: 300 psi
Acetone: 800 cm^3

Flight data: Parachute release time: 10 sec
Cargo release time: 12 sec
Launch angle: 5° into wind
Launch interval: 3 min
Apogee: 1700 ft (est)

Series C 12A (flights 117-118)
Series C 12B (flights 119-121)

Date: 23 August 1963, 1430 hours

Meteorological data: Wind: SW/3 knots
Sky cover: Patches of light fog. Broken clouds (strato cu) at 1200 ft (est)
Temp: -5.6C
R. H: 100%
Visibility: 4 miles

Vehicle data: Type: CRICKET — Long cargo chamber
Launch pressure: 75 psi
Propellant pressure: 280 psi
Acetone: 800 cm^3

Flight data: Launch angle: 5° into wind
Apogee: 1400 ft (est)
Launch interval: 8 min
Reagent: Group A: 10 oz Phloroglucinol (commercial grade, ball-milled to particle), sizes 0.5 μ to 5.0 μ

Series C 12A (flights 117-118) (Cont'd)
Series C 12B (flights 119-121)

Flight data: (Cont'd)
Reagent: Group B: 15 oz dry ice ($\frac{1}{4}$ - $\frac{3}{4}$ in.)
Timing: Group A: Parachute release - 8 sec
Cargo release - 10 sec
Group B: Parachute release - 8 sec
Cargo release - 12 sec

Series C 13 (flights 122-126)

Date: 24 August 1963, 0845 hours

Meteorological data: Wind: Sfc calm
1200 ft SSE/3 knots
Sky cover: Strato cu, 9/10 at 1200 ft (est)
Temp: Sfc -8.1C
R. H: 80%
Precipitation: Snow showers occurring.
Visibility: Variable. $\frac{1}{8}$ mile during showers, 7 miles at other times.

Vehicle data: Type: CRICKET — Long compartment
Launch pressure: 75 psi
Propellant pressure: 300 psi
Acetone: 800 cm³
Reagent: Approx 14 oz dry ice ($\frac{1}{4}$ - $\frac{3}{4}$ in.)

Flight data: Launch angle: 15° into wind
Apogee: 1200 ft (est)
Launch interval: 5 min
Parachute release time: 7 sec
Cargo release time: 20 sec

Series C 14 (flights 127-135)

Date: 4 September 1963, 2100 hours

Meteorological data: Wind: ESE/14 knots
Sky cover: Fog, estimated 300 ft thick
Temp: Sfc -6.7C
R. H: 100%
Droplet sizes (diam μ): Min 5.4, Max 284.0, Mean 31.8
Some ice crystals (hexagonal and columnar) 20-40 μ diam
Visibility: 250 yards

Vehicle data: Type: CRICKET — Long compartment
Reagent: Approx 15 oz dry ice ($\frac{1}{4}$ - $\frac{3}{4}$ in.)
Launch pressure: 75 psi
Propellant pressure: 350 psi (gaseous CO_2)
Acetone: None

Flight data: Launch angle: Vertical
Apogee: 300 ft (est)
Parachute release: 4 sec
Cargo release: 6 sec

APPENDIX B

Series L 1 (flights 1-5)

Date: 23 August 1963, 1100 hours

Meteorological data: Wind: Calm to SSE/3 knots
Sky cover: Fog (estimated 150 ft thick)

Temp:			
Sfc	-3.4C	600 ft	-5.6C
100 ft	-3.8C	700 ft	-5.4C
200 ft	-3.9C	800 ft	-4.8C
300 ft	-4.4C	900 ft	-4.8C
400 ft	-5.2C	1000 ft	-4.8C
500 ft	-5.0C	1100 ft	-4.9C

R. H: 100%
Droplet sizes (diam μ): Min 12.0, Max 84.3, Mean 49.0
Some ice crystals of approx 80 μ diam
Precipitation: Some freezing rain with few snow flakes before, during, and after seeding
Visibility: Approx 150 yards

Vehicle data: Type: CRICKET — Launch tube only
Launch pressure: 200 psi
Reagent: Approx 20 oz dry ice (fines to 2 in.)

Flight data: Launch interval: 60 sec
Launch angle: 5° from the vertical

Series L 2 (flights 6-16)

Date: 29 August 1963, 0740 hours

Meteorological data: Wind: SE/4 knots
Sky cover: Fog (estimated top at 100 ft)
Temp: -10.7C
R. H: 100%
Droplet sizes (diam μ): Min 5.3, Max.158, Mean 25.0
Ice crystals: Min 26.3, Max 100, Mean 54.5
Aerosols: None visible to the naked eye. Some ice crystals noted in impactor samples before seeding; more after seeding.
Visibility: Approx $\frac{1}{8}$ mile.

Vehicle data: Type: Launcher only
Reagent: Approx 12 oz dry ice ($\frac{1}{4}$ - $\frac{3}{4}$ in.)
Launch pressure: 100 psi

Flight data: Launch angle: 10°
Apogee: 65 ft (est)
Launch interval: 4 min
Dispersal: Dry ice was placed directly into the launch tube and blown into the air with 100 psi. These particles reached heights of 60-70 ft and spread into columns about 12 ft in diameter

APPENDIX C

Series B 1 (flights 1-5)

<u>Date</u>: 21 August 1963, 2115 hours

<u>Meteorological data:</u> Wind: Calm

Sky cover: Fog approx 100 ft thick

Temp:

Sfc	- 8.3C	700 ft	-8.8C
100 ft	-10.0C	800 ft	-8.6C
200 ft	-10.0C	900 ft	-8.5C
300 ft	-10.0C	1000 ft	-8.4C
400 ft	-10.0C	1100 ft	-8.2C
500 ft	-10.0C	1200 ft	-8.1C
600 ft	- 9.4C		

R. H: 100%

Droplet sizes (diam μ): Min 12.7, Max 86.0, Mean 30-35

Visibility: 200 yards

<u>Vehicle data</u>: Type: A 100 gram balloon (tethered)

Cargo: Dry ice, approx 10 oz ($\frac{1}{4}$ - $\frac{3}{4}$ in.)

<u>Flight data:</u> Launch interval: 5 minutes

Dispersal: A column, approx 55 feet in diameter, resulted from one explosion

Series B 2 (flight 6)

<u>Date</u>: 21 August 1963, 2345 hours

<u>Meteorological data:</u> Wind: NNE/2 knots

Sky cover: light fog; top at 100 ft (est)

Temp:

Sfc	-10.0C	700 ft	-10.0C
100 ft	-10.0C	800 ft	- 9.3C
200 ft	-10.0C	900 ft	- 8.8C
300 ft	-10.0C	1000 ft	- 8.8C
400 ft	-10.0C	1100 ft	- 8.9C
500 ft	-10.0C	1200 ft	- 8.8C
600 ft	-10.0C		

R. H: 100%

Visibility: Approx 200 yards

Vehicle data: Type: Blimp-balloon (Seyfang No. 1004) tethered

APPENDIX D

Series S 1

Date: 29 August 1963, 0950 hours

Meteorological data: Wind: SE/4 knots
Sky cover: Patches of ground fog
Temp: -11.2C
R. H: 84-100% (patchy fog) measured at 84% in clear area
Visibility: 1/8 mile in ground fog (3 miles in clear)
Aerosol:

Upwind from poles:

	Diameter (μ)		
Type precip:	Min	Max	Mean
Water:	5.3	158.0	25.0
Ice crystals:	26.3	100.0	54.5

Downwind from poles:

Water:	10.6	230.3	57.8
Ice crystals:	15.8	290.0	89.8

Mostly plane, regular, branched in secular or broad-branched. Many resemble flowers.

Series S 2

Date: 3 September 1963, 2010 hours

Meteorological data: Wind: SE/8 knots
Sky cover: Ground fog; depth 150 ft
Temp: Sfc -6.1C
R. H: 100%
Visibility: 1/4 mile
Aerosols: Some drifting snow and some ice crystals visible:

	Diameter (μ)		
Type precip:	Min	Max	Mean
Water:	5.4	284	31.8

Ice crystals: Some 20-40 μ: hexagonal and columnar

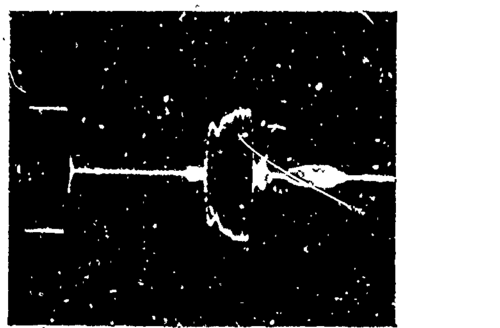

FIG. 6. A representative sample of the experimental data. Horizontal scale, 500 μsec/div; vertical scale, 0.2 V/div; pulse length, 700 μsec; and frequency, 100 kHz.

power points. It was necessary to use a small receiving hydrophone to avoid the spatial averaging that is performed automatically by a large hydrophone. The small, omnidirectional receiving hydrophone of diameter 5.2 mm used in the experiments had a broad bandwidth, so it could be used at each frequency.

In the experiments, a continuous oscillator was gated so as to form signals of 700-μsec duration. This produced an acoustic pulse in the water of length 1.05 m that contained 70 cycles at 100 kHz. The gated output of the oscillator served as the input of a power amplifier that drove the transducer. The received signal was amplified by a tuned radiofrequency amplifier whose output was displayed on a cathode-ray oscilloscope from which the magnitude of the scattered pulse was measured. A representative photograph of the received signal is shown in Fig. 6.

The system was calibrated by separating the projector and receiver a distance r_{cal} of approximately 3.4 m and orienting them towards one another. Let V_{cal} be the peak-to-peak voltage of the received signal for this configuration. Next, the transducers were arranged as shown in Fig. 5. Let r_{tp} be the travel path measured along the acoustic axes of the transducers from the projector to the specular reflection point on the surface to the receiver, and let V_{tp} be the peak-to-peak voltage of the received signal in this configuration. The distances r_{cal} and r_{tp} are large enough to permit one to use the inverse-distance law for pressure amplitudes, so that as long as one is careful to use the same source signals for the two measurements, one can calculate an experimental value σ_E from the formula

$$\sigma_E = (V_{tp} r_{tp} / V_{cal} r_{cal})^2. \tag{1}$$

This definition of σ_E yields a value of unity when the surface is a perfect, plane reflector. The case of a perfect, plane reflector is discussed in Sec. II-C of the companion paper, where it is shown that one would obtain a value of unity for the scattering coefficient only

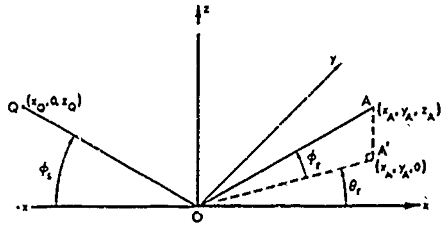

FIG. 7. The angular variables used in the experimental measurements.

if the value of $J(0,0)$ were normalized to a plane at right angles to the axis of the transducer. It is evident that this normalization was introduced experimentally when V_{cal} was measured with the transducers facing one another. Consequently, as suggested in Eq. 24 of the companion paper,[11] the quantity that should be compared with the present experimental values is σ/c_Q.

IV. THEORETICAL FORMULAS FOR THE MODEL

It is evident from the preceding section that Eq. 35 of the companion paper is the relevant equation for the present model study. In order to examine more easily the predictions of this solution, it is desirable to introduce the actual variables used in the experimental studies. These variables are illustrated in Fig. 7. The source Q was always held at a fixed position in the (x,z) plane while the receiver A was moved by varying one of the two angles θ_r and φ_r. In the majority of the measurements, θ_r was held constant, equal to zero. In terms of these variables, some of the direction cosines introduced in the companion paper (Eqs. 6 and 7) become

$$\begin{aligned} c_A &= \sin\varphi_r, \\ c_Q &= \sin\varphi_i, \\ c &= c_A + c_Q = \sin\varphi_r + \sin\varphi_i, \\ a &= -\cos\varphi_i + \cos\varphi_r \cos\theta_r, \\ b &= \cos\varphi_r \sin\theta_r. \end{aligned} \tag{2}$$

If the formula for σ, Eq. 35 of the companion paper is expanded in these variables with the further specification that $\theta_r = 0$, one finds

$$\sigma_T(\varphi_i, \varphi_r) = \frac{G(\sin\varphi_r + \sin\varphi_i)^4}{8\pi[G^2(\sin\varphi_r + \sin\varphi_i)^4 + (\cos\varphi_r - \cos\varphi_i)^2]^{\frac{3}{2}}} \tag{3}$$

where G is a dimensionless constant defined by

$$G = kh^2/L. \tag{4}$$

The parameter G characterizes the relief and the coherence of the surface in terms of the wavelength.

The subscript T has been applied to σ to distinguish this theoretical value from the experimental value σ_E.